DYNAMIC CHARACTERISTICS OF FAR-FIELD RADIATION OF CURRENT MODULATED PHASE-LOCKED DIODE LASER ARRAYS

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1. INTRODUCTION

The aim of this project was to study the dynamic characteristics of the radiation emitted by phase-locked diode laser arrays under conditions obtaining in high data rate communication systems. These lasers are of interest for optical communication systems because they are small, lightweight, very efficient devices and their output can be directly modulated by varying the drive current. However multiple emitter arrays have generally been observed to emit in multiple-lobed far-field patterns[1-4] which are disadvantageous for either optical fiber or line-of-sight communication applications. The dynamic behavior of the radiation pattern under fast pulsed operation or drive current modulation in excess of 500 MHz such as required for 250 Mbit/s communication systems is of particular interest[5-8].

The initial plan, which was overly ambitious given the complexity of the experiments and the project duration, was to study several types of phase-locked diode laser arrays, including gain-guided, index-guided and offset stripe arrays, operating under both fast pulsed and high frequency sinusoidal modulation. Samples of each of these types of lasers were acquired along with two of the new flared waveguide Y-coupled devices[9]. Unfortunately time did not permit the detailed comparison and analysis of all of these different types of lasers and measurements were in fact made only on ten emitter gain-guided and Y-coupled devices and then only in fast pulsed operation.

The technical approach taken in this project was an extension of the streak camera technique we introduced earlier for observing the time evolution of either the far-field pattern or the near-field of a diode laser array[5,6]. The addition of video frame grabbing capability to the streak camera system made it possible to record the temporal behavior of the entire radiation pattern at the same time rather than being restricted to at most two spatial windows as was the case earlier. It was then possible to process these records to obtain cross correlations of the near-field intensity of the emitters in the array; noise spectra; and halftone and graphical representations of the near- and far-field intensity versus time for a single laser pulse. These data together with other measurements on the device in question such as the emission spectrum and the time delay between the drive current pulse and the initiation of lasing can then be used to understand the physical processes responsible for its dynamic behavior.

In the next section the experimental setup and data acquisition procedure is discussed while section 3 is devoted to a description of the data handling and analysis methods and software. Section 4 presents examples of the data acquired with the system and Section 5 contains some concluding remarks.

2. EXPERIMENTAL

The design of this experiment evolved from that originated by DeFreez and Elliott[5,6] in the first streak-camera measurements of the fast pulse response of phase-locked, multiple quantum well diode laser arrays. The use of a streak-camera is a significant departure from the more traditional approach of observation of the emission with a photodiode since the streak camera permits measurements to be made on a single pulse with a time resolution of a few picoseconds. This makes studies of rapidly evolving events which may vary from pulse to pulse possible. In addition the streak camera provides a three-dimensional record of intensity versus space and time which makes possible the simultaneous observation of the evolution of the intensity profile for each of the individual emitters in the array or particular spatial features of the far-field. These features of the streak camera system are essential for studies of the noise properties of the emission in the near-field and ultimately for unraveling the complex interplay of the array modes.

It is also possible to obtain intensity profiles for a number of individual laser pulses and average these to give the optical response which is observed with more conventional techniques. Fourier transforms and statistical analyses may be done on the individual and averaged intensity profiles to provide information on the transient response of the array. In our earlier work[5,6] simultaneous observation of at most two portions of the radiation pattern were possible since the temporal analyzer of the Hamamatsu C979 streak camera allows for the definition of only one or two spatial windows. In this work video frame grabbing capability was added to the streak camera system making full use of the intensity information available on each of the individual emitters in the array.

The streak camera video frame-grab system used to measure the time evolution of the light intensity from the array is illustrated in Figure 1. The diode laser under study is driven from zero to $1.5 I_{th}$ by 1 ns risetime 50 ns duration current pulses provided by an Avtech AVO-2-C pulser impedance matched to the diode laser. The lasers themselves were modified in that any fine (25 μm dia.) gold wires were removed and replaced with 100 μm wide gold straps to reduce high frequency inductive loading that would preclude a fast risetime current pulse. The light emitted by the laser is collected by a 20×, 0.4 N.A. microscope objective and directed onto the input slit of the streak camera for recording the far-field intensities. The near-field data is obtained by removing the input slit and imaging the output facet of the diode laser onto the location normally occupied by the input slit.

The Avtech current pulser and the streak camera are triggered synchronously by a video frame pulse extracted from the free-running vidicon output by the sync-stripper. This method of triggering ensures that the output from the streak camera coincides with the beginning of a video frame. Consistent positioning of the streak trace at the
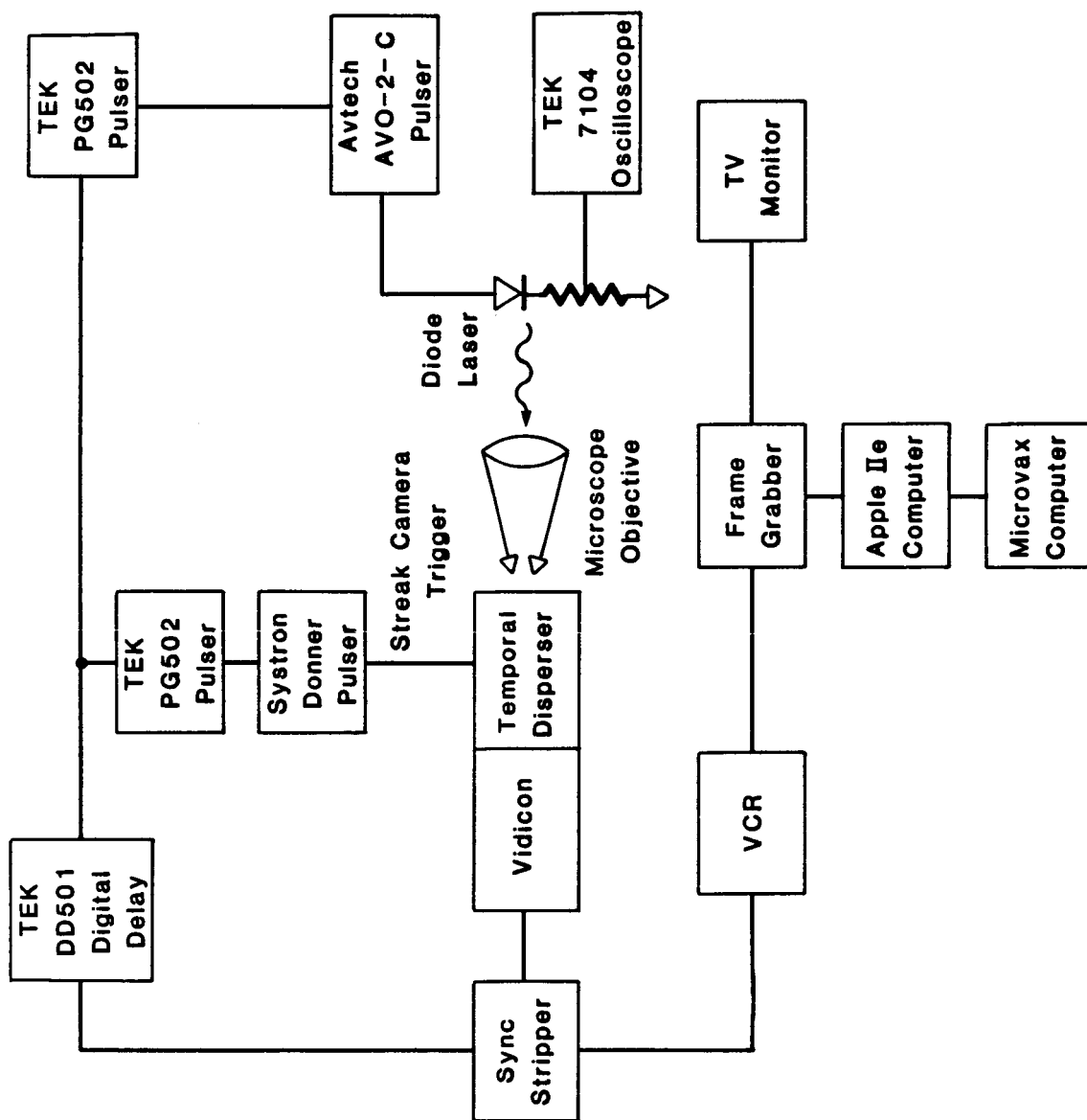
Figure 1. Schematic diagram of the streak camera video frame-grab system.

beginning of the video frame is essential for any type of temporal analysis involving pulse to pulse comparison or averaging over several pulses. The duration of the streak trace depends on the sweep speed of the camera and can be as short as 0.512 ns and as long as 5.6 ns. Only the slowest sweep speed was used in this study and all records correspondingly are 5.6 ns in duration. The ability to vary the relative timing of the current pulse to the laser and the streak camera trigger allows any portion of the 50 ns light pulse to be recorded, i.e., it is possible to view the beginning of the light pulse when one expects to see relaxation oscillations and other transient behavior or the latter part of the 50 ns pulse when quasi cw behavior is expected.

A video cassette recorder (VCR) is used to record, in frames separated by one second time intervals, the streak camera intensity versus space and time images of individual laser pulses. These stored streak traces are then digitized with a video frame grabber and transferred to an Apple IIe microcomputer. The 65536 pixel digitized images can then either be transferred directly to a MicroVAX II or preprocessed by the Apple.

3. SOFTWARE AND DATA ANALYSIS

Software to transform the full digitized images into a form suitable for rendering halftone reproductions on a laser printer was written for the MicroVAX. A graphics program was also implemented to provide the means to present the intensity versus time and space data as the plane projection of a three-dimensional plot.

Assembly language code was generated for the Apple which enables it to reduce the data from the 256 × 256 arrays provided by the frame grabber to an N × 256 array where N is the number of spatial windows into which one may wish to partition the intensity versus time and space image. For noise or statistical analysis of near-field measurements on ten stripe devices ten windows are normally defined, each window enclosing the intensity profile of an emitter. These windows should be chosen to be of equal width to ensure that the same amount of background is present in each of the individual intensity profiles. The Apple IIe software calculates the average intensity over the width of each window for each of the 256 time channels. This window-averaged intensity data is then written to files on floppy disks and subsequently transferred to the MicroVAX II computer for in-depth statistical analysis.

The statistical analysis software was designed with the goal of understanding the physics of the transient response of the phased-locked diode laser arrays. To this end software capable of performing various averages and Fourier transforms and cross correlations on the N × 256 data arrays was generated. The Fourier transforms of the

single pulse intensity versus time record of single emitters yields a set of noise spectra particular features of which may be associated with the physical processes occurring in the laser. Either averages of these noise spectra or Fourier transforms of averages of the single pulse versus time records may be used to remove the pulse to pulse variations. Consistent shot to shot features such as the relaxation oscillation frequencies may then be determined from this averaged data.

The cross correlation between the single emitter intensity records provides information on the strength of the coupling between the emitters in the array and on the competition between the array modes. Any change in cross correlation with time reflects a shift in the relative phases of the two emitters and yields information on the stability of phase-locking.

It is also possible to sum all N records in a data array to generate the intensity versus time behavior of the entire laser array or to average each of the N records over time and over several pulses to yield the average near-field intensity which could then be compared with a cw measurement of the near-field and perhaps reveal the effect of thermal transients on the array.

4. RESULTS

Figure 2 is a halftone reproduction of the near-field intensity versus time of a ten emitter gain-guided array and Figure 3 is that of a flared waveguide Y-coupled (FYCL) array. Note the repetitive spiking in the emission of the the right hand half of the FYCL array while the left hand emitters are more stable. Figures 4 and 5 are 3D perspectives generated from the same data as displayed in Figures 2 and 3 respectively. Figure 6 is an expanded view of the first third of Figure 5.

The time evolution of the far-field of the same FYCL laser is displayed in halftone in Figure 7. Note that the strong central lobe and two weaker side lobes are fully formed at the initiation of lasing. This indicates that the array is locked in-phase essentially instantaneously[10]. The wobble evident in the central lobe may be due to the strong spiking in one half of the array.

Figure 8 displays the cross correlation between the fifth emitter and the others in a gain-guided array illustrating the strong correlation between adjacent emitters, e.g., fourth, fifth and sixth, and the reduced correlation between emitters which are well separated. Figure 9 is the Fourier transform of the intensity of the gain-guided array shown in Figures 2 and 4.
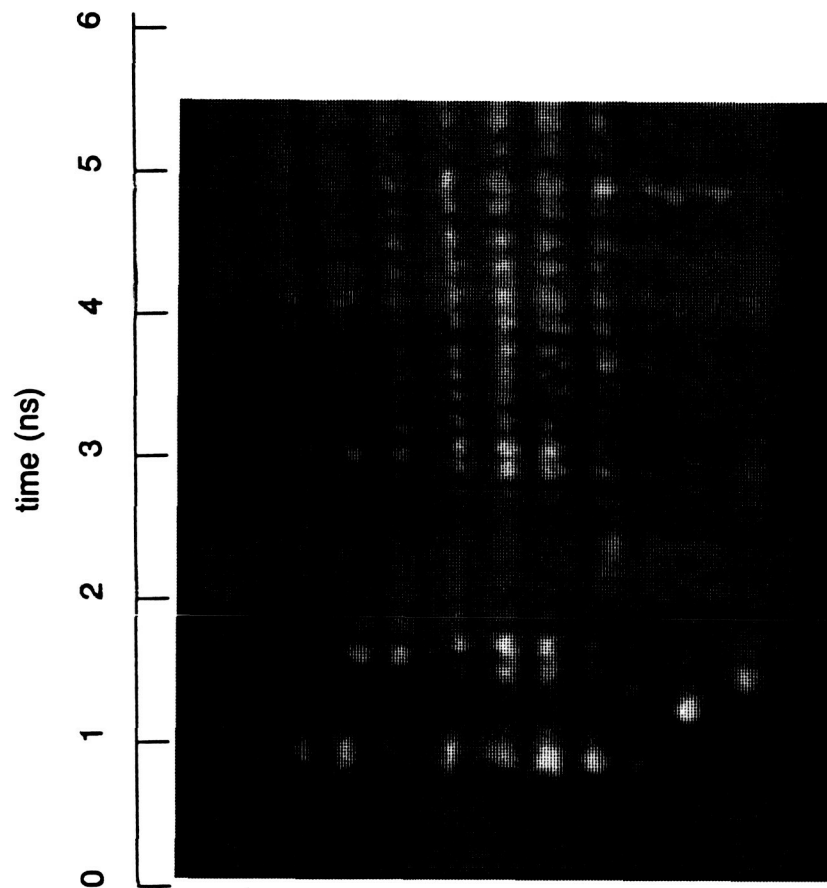
Figure 2. Time evolution of a ten emitter gain-guided laser array near-field pattern.
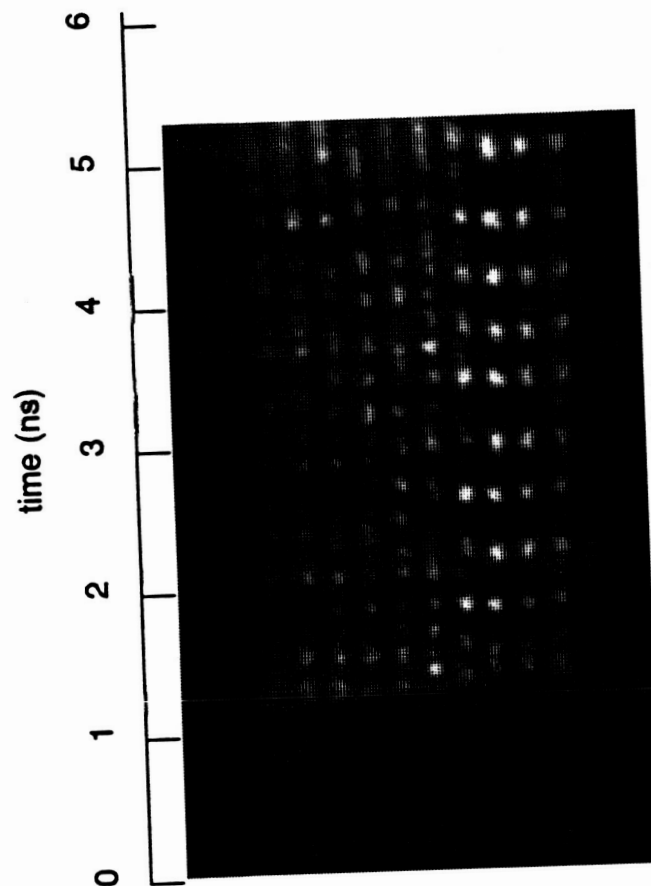
Figure 3. Time evolution of a FYCL array near-field pattern.
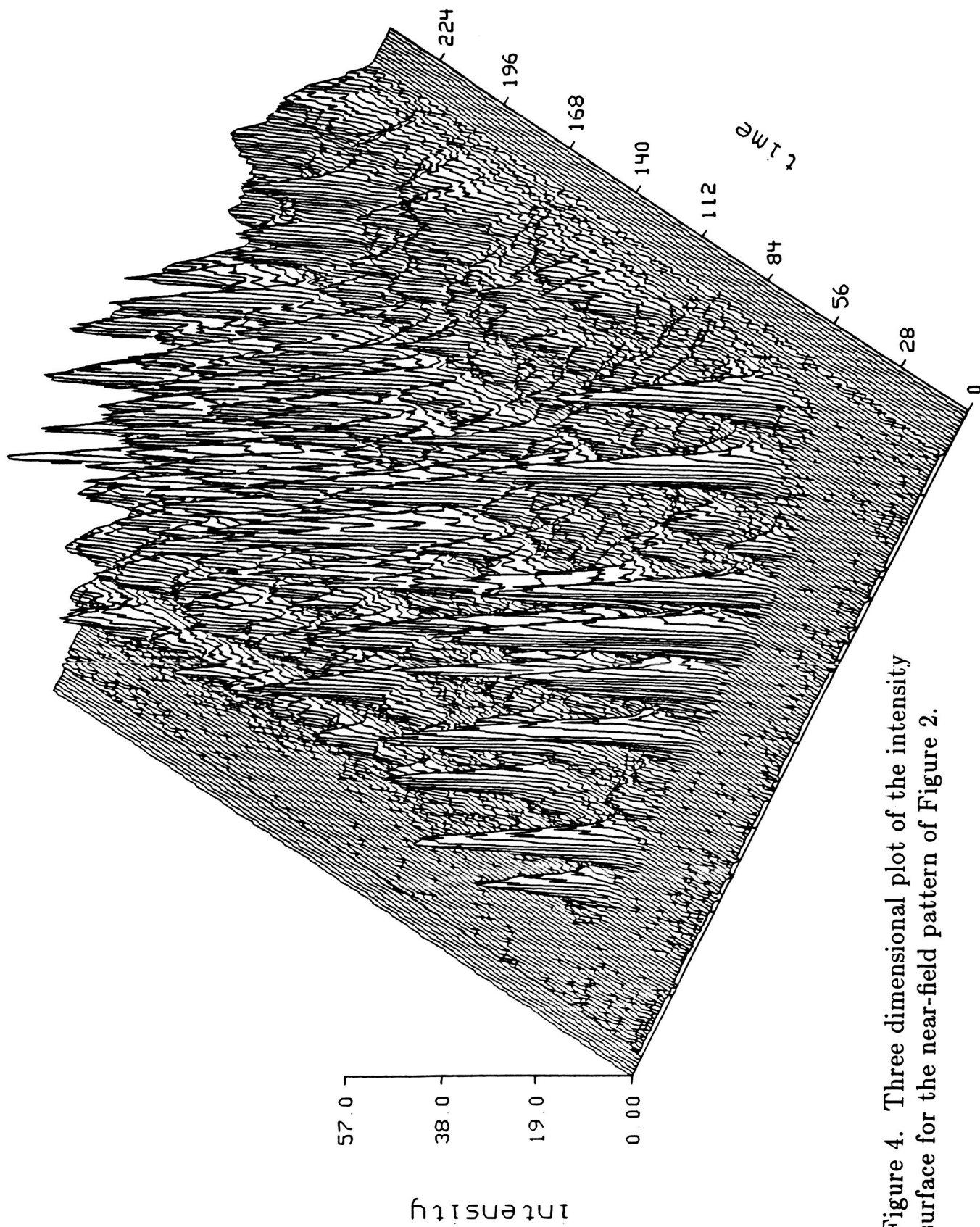
Figure 4. Three dimensional plot of the intensity surface for the near-field pattern of Figure 2.
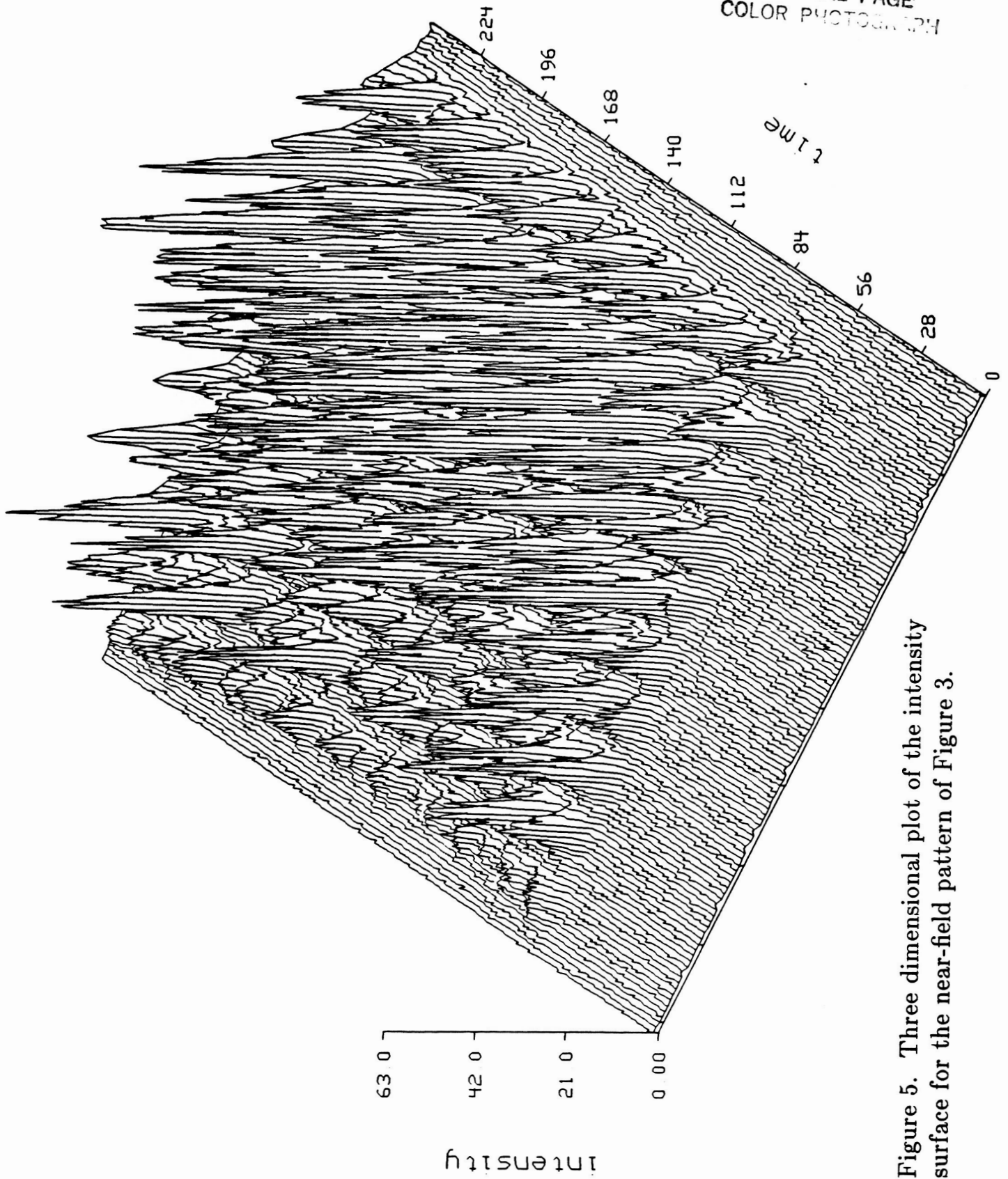
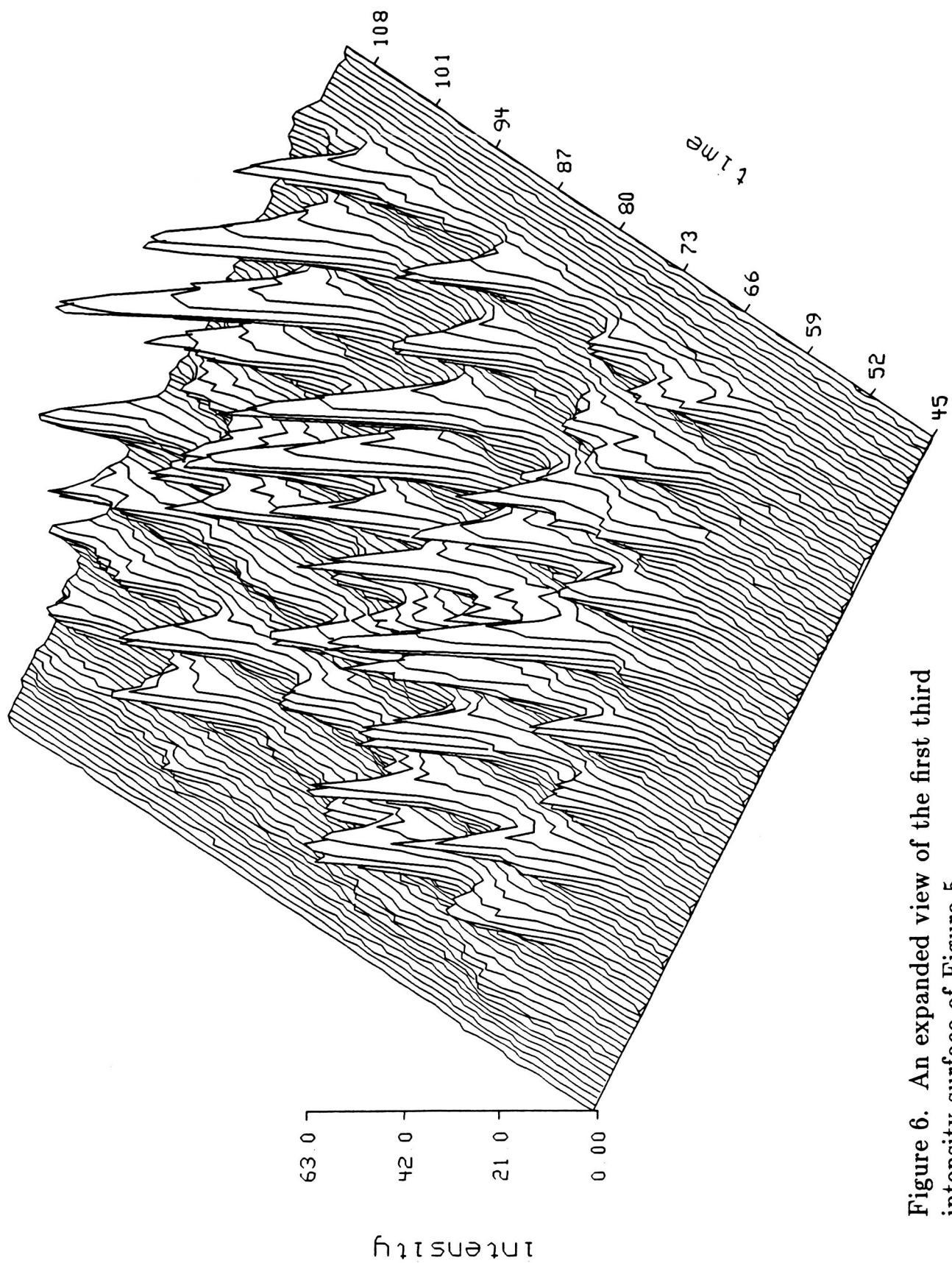Figure 5. Three dimensional plot of the intensity surface for the near-field pattern of Figure 3.

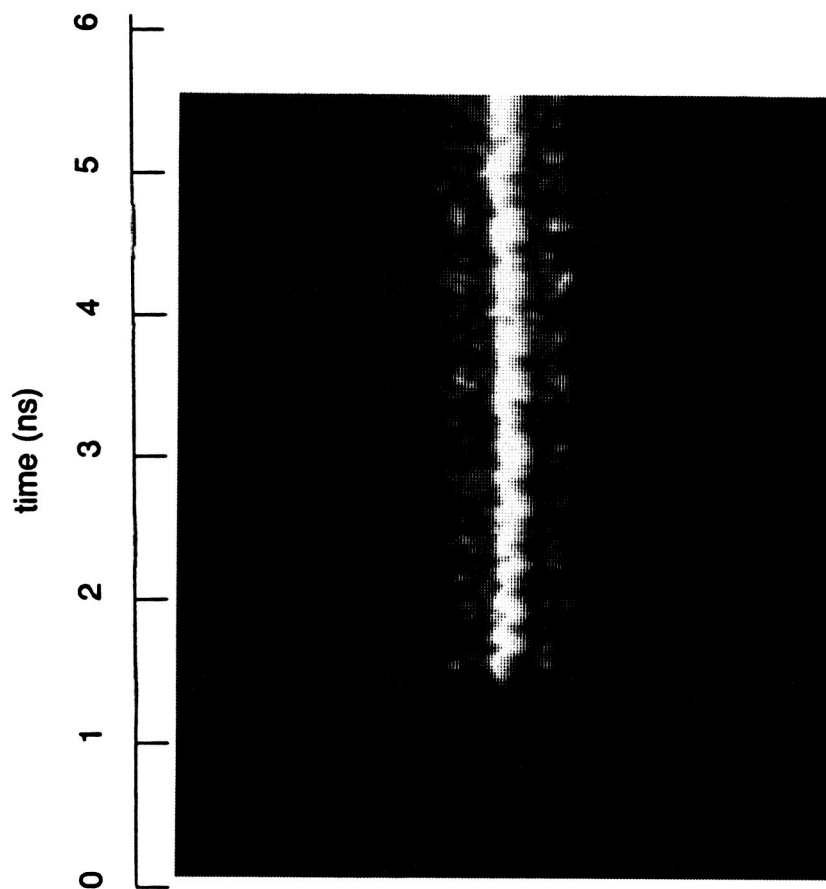Figure 6. An expanded view of the first third intensity surface of Figure 5.

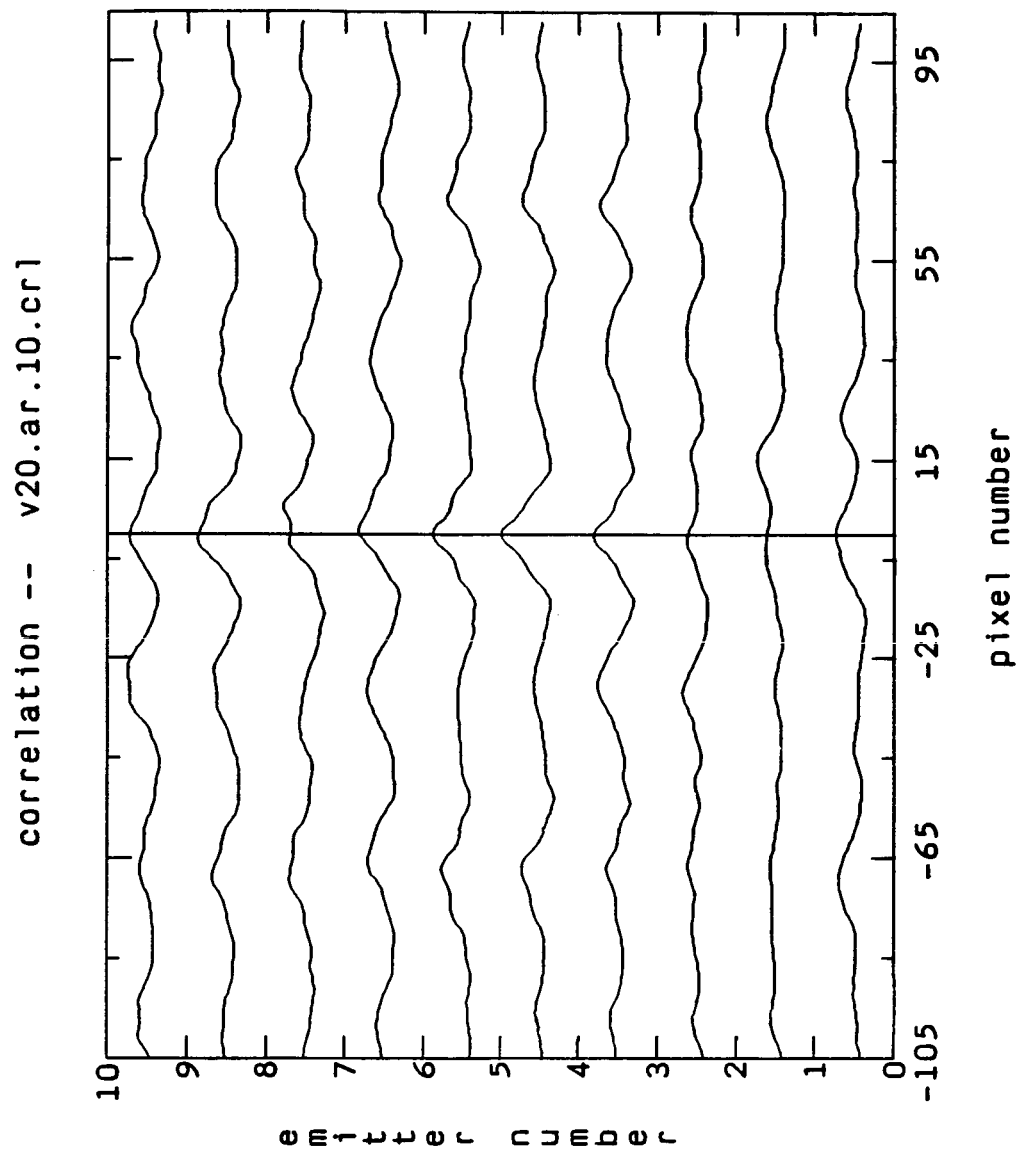Figure 7. Time evolution of the FYCL array far-field pattern.

Figure 8. Cross correlation between the fifth emitter and the others in a 10 stripe gain-guided laser array.
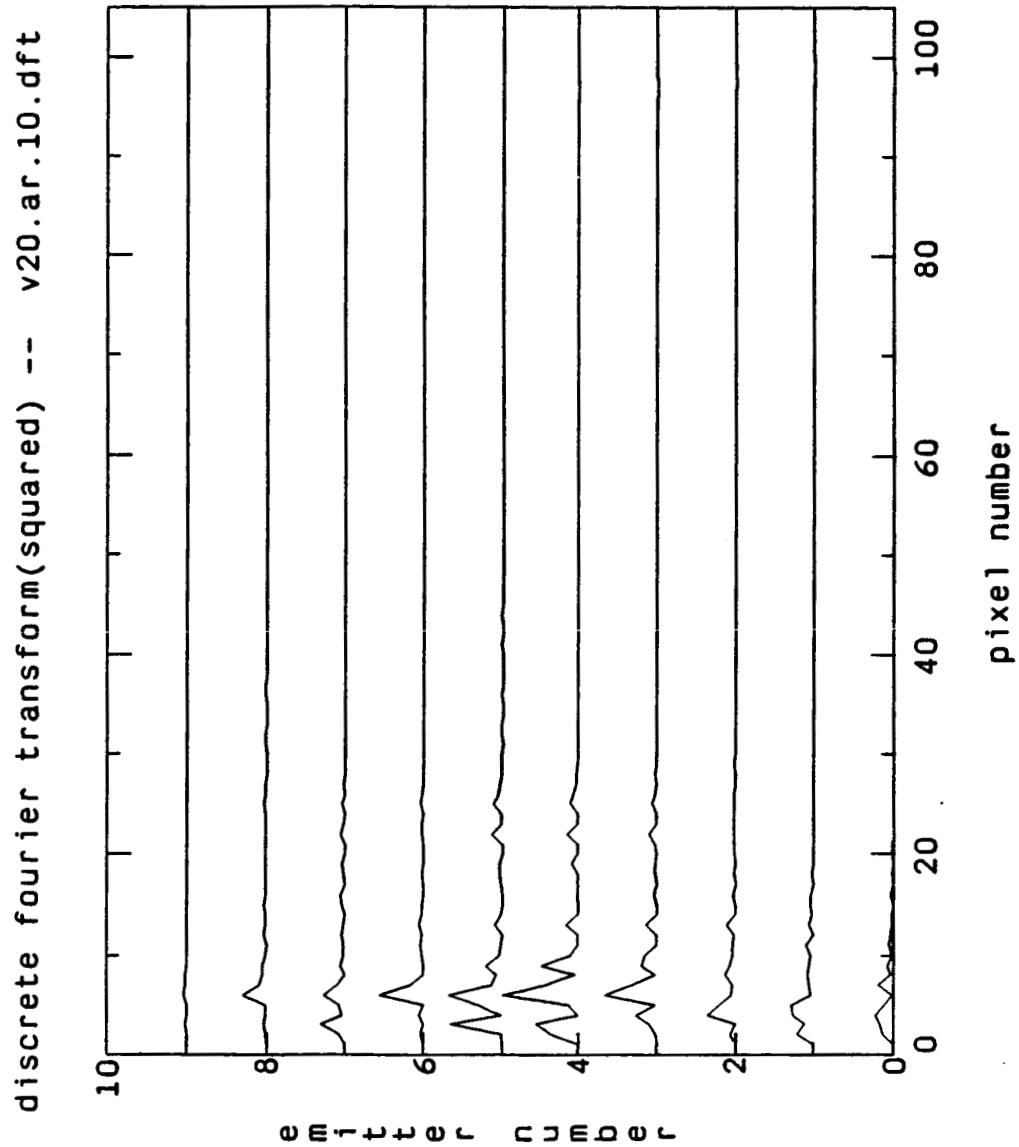
Figure 9. Fourier transform of the near-field intensity for the gain-guided array shown in Figures 2 and 4.

5. CONCLUSION

A versatile and powerful streak camera/frame-grabber system for studying the evolution of the near- and far-field radiation patterns of diode lasers has been assembled and tested. Software needed to analyze and display the data acquired with the streak camera/frame-grabber system has been written and the total package used to record and perform preliminary analyses on the behavior of two types of laser, a ten emitter gain-guided array and a FYCL array. Examples of the information which can be gathered with this system are presented in Figures 2 through 10.

Unfortunately insufficient time remained to complete the detailed study of all the types of lasers originally planned and to fully exploit the capabilities of the data acquisition and handling system. Nor was it possible to study the behavior of these lasers under sinusoidal current modulation with the devices dc biased near threshold.

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